Chapter 5
Horizontal Control Survey Techniques

5-1. Introduction

a. General. Primary horizontal control (Third Order Class I or higher) is established to serve as a basic framework for large mapping projects, to establish new horizontal control in a remote area, or to further densify existing horizontal control in an area.

b. Instruments. Minimum instrument requirements for the establishment of primary control will typically include a repeating theodolite having an optical micrometer with a least-count resolution of six seconds (i.e., 6") or better; a directional theodolite having an optical micrometer with a least count resolution of one arc-second; an EDM capable of a resolution of 1:10,000; or a total station having capabilities comparable to, or better than, any of the instruments just detailed.

c. Monumentation. Primary horizontal control points not permanently monumented in accordance with criteria and guidance established in EM 1110-1-1002 should meet the following minimum standards:

(1) Markers. Primary horizontal control points shall be marked with semi-permanent type markers (e.g., re-bar, railroad spikes, or large spikes). If concrete monuments are required, they will be set prior to horizontal survey work. These monuments will be established in accordance with EM 1110-1-1002.

(2) Installation. Primary horizontal control points shall be placed either flush with the existing ground level or buried a minimum of one-tenth of a foot below the surface.

(3) Reference marks. Each primary control point should be referenced by a minimum of two points to aid in future recovery of that point. For this reference, well defined natural or manmade objects may be used. The reference point(s) can be either set or existing and should be within one hundred feet of the control point.

(4) Sketches. A sketch shall be placed in a standard field survey book. The sketch, at minimum, will show the relative location of each control point to the reference points and major physical features within one hundred feet of the point.

d. Redundancy. A minimum of three to four repeated angle measurements will be made for establishing primary control points--one angle and one distance will not be sufficient. When using high precision total stations, only half as many readings are generally required (two data set collections). With EDM distance measurements, a minimum of two readings shall be taken at each setup and recorded in a standard field book. The leveled height of the instrument and the height of the reflector shall be measured carefully to within 0.01 foot and recorded in the field book. Each slope distance shall be reduced to a horizontal distance using either reciprocal vertical angle observations or from the known elevation of each point obtained from differential leveling.

e. Repeating theodolite. If a repeating theodolite (e.g., Wild T1) is used for the horizontal angles, the instrument will be pointed at the backsight station with the telescope in a direct reading position, and the horizontal vernier set to zero degrees. All angles shall then be turned to the right, and the first angle recorded in a field book. The angle shall be repeated a minimum of four times (i.e., two sets) by alternating the telescope and pointing in the direct and inverted positions. The last angle will also be recorded in the field book. If the first angle deviates more than five seconds (5") from the result of the last angle divided by four, the process shall be repeated until the deviation is less than or equal to five seconds. Multiples of 360 degrees may need to be added to the last angle before averaging. The horizon shall be closed by repeating this process for all of the sights to be observed from that location. The foresight for the last observation shall be the same as the backsight for the first observation. If the sum of all the angles turned at any station deviates more than ten seconds (10") from 360 degrees, the angles shall be turned again until the summation is within this tolerance.

f. Directional theodolite. If a directional theodolite (e.g., Wild T2, Wild T3) is used for the horizontal angles, the instrument shall be pointed at the backsight station with the telescope in a direct reading position and the horizontal scales set to within ten seconds (10") of zero degrees. The scales shall be brought into coincidence and the angle read and recorded in the field book. The angles shall then be turned to each foresight in a clockwise direction, and the angles read and recorded in a field book. This process will continue in a clockwise direction and shall include all sights to be observed from that station. The telescope shall then be inverted and the process repeated in reverse order, except the scales are not to be reset, but will be read where it was originally set. The angles between stations may then be computed by differencing the direct and reverse readings. This process shall be repeated three times for a total of three direction set readings.

g. Horizontal distances. To reduce EDM slope distances to horizontal, a vertical angle observation must be obtained from each end of each line being measured. The vertical angles shall be read in both the direct and inverted scope positions and adjusted. If the elevations for the point on each end of the line being measured are obtained by differential leveling, then this vertical angle requirement is not necessary.

h. Targets. All targets established for backsights and foresights shall be centered directly over the measured point. Target sights may be a reflector or other type of target set in a tribrach, a line rod plumbed over the point in a tripod, or guyed in place from at least three positions. Artificial sights (e.g., a tree on the hill behind the point) or hand held sights (e.g., line rod or plumb bob string) will not be used to set primary control targets.

e. Calibration. All total stations, EDM, and prisms used for primary control work shall be serviced regularly and checked frequently over lines of known length. Calibration should be done at least annually. Theodolite instruments should be adjusted for collimation error at least once a year and whenever the difference between direct and reverse reading of any theodolite deviates more than thirty seconds from 180 degrees. Readjustment of the cross hairs and the level bubble should be done whenever misadjustments affect the instrument reading by more than the least count of the reading scales of the theodolite.

5-2. Secondary Horizontal Control

a. General. Secondary horizontal control (Third Order Class II or lower) is established to determine the location of structure sections, cross sections, or topographic surfaces, or to pre-mark requirements for small to medium scale photogrammetric mapping.

b. Requirements. Secondary horizontal control requirements are identical to that described for primary horizontal control with the following exceptions.

(1) Monumentation. It is not required for secondary horizontal control points to have two reference points.

(2) Occupation. Secondary horizontal control points can be established by one angle and one distance.

(3) When a total station or EDM is used, a minimum of two readings shall be taken at each setup and recorded in a standard field book.

(4) If a repeating theodolite is used for the horizontal angles, the angle measurement shall be repeated a minimum of two times by alternating the telescope and pointing in the direct and inverted positions.

(5) If a directional theodolite is used for the horizontal angles, the process (described for primary control) shall be repeated two times for a total of two data set collections.

5-3. Traverse Survey Standards

a. General. A survey traverse is defined as the measurement of the lengths and directions of a series of straight lines connecting a series of points on the earth. Points connected by the lines of traverse are known as traverse stations. The measurements of the lengths and directions are used to compute the relative horizontal positions of these stations. Traversing is used for establishing basic area control surveys where observation of horizontal directions and distances between traverse stations, and elevations of the stations, must be determined. Astronomic observations and GPS surveys are made along a traverse at prescribed intervals to control the azimuth of the traverse. The interval and type of astronomic observation will depend upon the order of accuracy required and the traverse methods used.

b. Traverse types. There are two basic types of traverses, namely, closed traverses and open traverses.

(1) Closed traverse. A traverse that starts and terminates at a station of known position is called a closed traverse. The order of accuracy of a closed traverse depends upon the accuracy of the starting and ending known positions and the survey methods used for the field measurements. There are two types of closed traverses.

(a) Loop traverse. A loop traverse starts on a station of known position and terminates on the same station. An examination of the position misclosure in a loop traverse will reveal measurement blunders and internal loop errors, but will not disclose systematic errors or external inaccuracies in the control point coordinates.

(b) Connecting traverse. A connecting traverse starts on a station of known position and terminates on a different station of known position. When using this type of traverse the systematic errors and position inaccuracies can be detected and eliminated along with blunders and accidental errors. The ability to correct measurement error depends on the known accuracy of the control point coordinates.

(2) Open traverse. An open traverse starts on a station of known position and terminates on a station of unknown position. With an open traverse, there are no checks to determine blunders, accidental errors, or systematic errors that may occur in the measurements. The open traverse is very seldom used in topographic surveying because a loop traverse can usually be accomplished with little added expense or effort.

c. Requirements. The following minimum guidelines should be followed for traverse procedures:

(1) Origin. All traverses will originate from and tie into an existing control line of equal or higher accuracy.

(a) Astronomic observation. If it is impossible to start or terminate on stations of known position and/or azimuth, then an astronomic observation for position and/or azimuth must be conducted. For Third Order surveys, astronomic azimuth observations are made at intervals along the traverse and at abrupt changes in the direction of the traverse. The placement of these astronomic stations is governed by the order of accuracy required.

(b) Traverse setup. The specific route of a new traverse shall be selected with care, keeping in mind its primary purpose and the flexibility of its future use. Angle points should be set in protected locations if possible. Examples of protected locations include fence lines, under communication or power lines, near poles, or near any permanent concrete structure. It may be necessary to set critical points below the ground surface. If this is the case, reference the traverse point relative to permanent features by a sketch, as buried points are often difficult to recover at future dates.

(c). Accuracy. Traversing is conducted under four general orders of accuracy:

- First Order
- Second Order
- Third Order
- Fourth Order

The order of accuracy for traversing is determined by the equipment and methods used to collect the traverse measurements, by the final accuracy attained, and by the coordinate accuracy of the starting and terminating stations of the traverse. The point closure standards in either Table 3-1 or FGCS 1984 must be met for the appropriate accuracy classification to be achieved.

5-4. Traverse Survey Guidelines

a. General. Survey traverse work involves several basic steps to plan and execute.

- researching existing control in the project area
- design survey to meet specifications
- determine types of measurements
- determine types of instruments
- determine field procedures
- site reconnaissance and approximate surveys
- install monuments and traverse stations
- data collection
- data reduction
- data adjustment
- prepare survey report

`b. Control traverses. Control traverses are run for use in connection with all future surveys to be made in the area of consideration. They may be of First, Second, Third, or Fourth Order accuracy, depending on project requirements.

(1) Preparation. Most project requirements will be satisfied with Second or Third Order accuracies. For a Second Order traverse, it is recommended that permanent points be established at

intervals of one mile or less, starting at a known point--preferably a National Geodetic Survey (NGS) published control point. Plan the traverse to follow a route that will be centered as much on the project area as possible, and avoiding areas that will be affected by construction, traffic, or other forms of congestion. The route should provide a check into other known points as often as practicable. After determining the route, it is best to then set permanent monuments (e.g., stakes, iron rods, brass caps in concrete, or some other suitable monument) at each angle point and any intermediate points desired. Refer to EM 1110-1-1002 for further guidance on survey markers and monumentation. Ensure there is a clear line of sight from angle point to angle point and determine an organized numbering or naming system to mark all points when set.

(3) Measurements. Manufacturer instructions for operation of the EDM or total station should be followed. When using an EDM or total station, a minimum of two readings will be made before moving to the next occupation point. All readings should agree within the resolution of the instrument or 0.001 foot of the original reading. Determination of angles should be made immediately after distance determination. Special care should be taken with the type of sights used for angle measurement--fixed rigid sights should be used, not hand held targets. For directional theodolite or total station angle measurements, at least three sets of angles should be made. Adequate results can be obtained with fewer angles if precision equipment is used. A horizon closure may be performed as a check.

(3) Reductions. All survey field notes should be carefully and completely reduced with the mean angle calculated in the field and recorded along with the sketch. All traverse adjustments should be made in the office. A sketch of the monument location should be made in the field and a detailed description on how to recover it should be recorded in writing. This information can be used for making subsequent record of the survey monument and survey report.

c. Right of Way traverse. A right of way traverse typically is a Third Order traverse, starting and ending on known points. This type of traverse is usually run with a transit and steel tape, EDM, or total station. The style of notes is similar to most traverses with the only difference being the type of detail shown. Fences are of particular importance in determining right of way limits, especially when working in an area not monumented. Notes for right of way traverses should be especially clear and complete for many times this type of traverse is the basis for legal or court hearings regarding true property corners. If a search for a corner is made and nothing is found, a statement should be written in the field book to this effect. Property title searches and deed research will generally be required to obtain appropriate existing descriptions, plans, and other documents which are generally available in the public record.

d. Stadia traverse. Uses of stadia traverses include rough or reconnaissance type surveys, checking on another traverse for errors, and control for a map being made by stadia methods on a very large scale. A stadia traverse typically is run along a route that will best suit the point location requirements of the survey. The stadia points or stadia angle points will be set at locations that will best recover desired information and will be set in protected locations for future use.

e. Compass traverse. A compass traverse is made to establish the direction of a line by compass measurements (i.e., no angles are turned). Distances are usually measured by stadia or paced.

f. Azimuth traverse. Compass bearings break the circle directions into four quadrants, while an azimuth measures direction from true North, South, or on some other base. Azimuths should always be determined as a right deflection from the base point to the reference object. Astronomical observations, GPS surveys, and specialized instruments such as gyro theodolites and gyro theodolite attachments are used to measure precise azimuths.

5-5. Traverse Classifications

a. General. Table 5-1 lists specific traverse requirements necessary to meet Second and Third Order type accuracies.

b. Second Order traverse. Second Order traverse is used extensively for subdividing an area between First and Second Order triangulation and First Order traverse. Second Order traverse must originate and terminate on existing First or Second Order control that has been previously adjusted.

c. Third Order traverse. Third Order traverse is normally used for detailed topographic mapping. Third Order traverse must start and close on existing control stations of Third or higher order accuracy.

Table 5-1. Traverse Requirements

Requirement	Second Order	Third Order
Horizontal Angles		
Instrument	0.2" - 1.0"	1.0"
Repetitions	6 - 8	2 - 4
Rejection Limit	4" - 5"	5"
Number of Courses between Azimuth Checks		
Steel Tape	25	35 - 50
EDM	12 - 16	25
Azimuth Closure		
Standard error	2.0"	5.0"
Azimuth Closure at Checkpoint		
Azimuth Checkpoint	3" per station	5" per station
or		
Azimuth Checkpoint	(10")*$N^{1/2}$	(15")*$N^{1/2}$
	where N is the number of stations carrying azimuth	

c. Lower Order. Traverses of lower than Third Order are used for controlling points when a relatively large error in position is permissible. For example, map compilation requirements for a horizontal control panel point for 1:50,000 mapping shall be located to within 6 meters of its true relationship to the basic control. For 1:25,000 mapping the requirement is usually to within 3 meters. The allowable errors permit accuracies to vary from generally 1 part in 500 to 1 part in 5000, depending on the distance the lower order traverse must travel, the type of control at the start of the traverse, the desired accuracy of the control point, and the methods and equipment used in the traverse. Using Third Order methods should be carefully considered, even though the points are not to be monumented permanently.

5-6. Triangulation and Trilateration

a. General. A triangulation network consists of a series of angle measurements that form joined or overlapping triangles in which an occasional baseline distance is measured. The sides of the network are calculated from angles measured at the vertices of the triangle. A trilateration network consists of a series of distance measurements that form joined or overlapped triangles where all the sides of the triangles and only enough angles and directions to establish azimuth are determined.

b. Networks. When practicable, all triangulation and trilateration networks will originate from and tie into existing coordinate control of equal or higher accuracy than the work to be performed. An exception to this would be when performing triangulation or trilateration across a river or some obstacle as part of a chained traverse. In this case, a local baseline should be set. Triangulation and trilateration surveys should have adequate redundancy and are usually adjusted using least squares methods.

c. Accuracy. Point closure standards listed in Table 3-1 must be met for the appropriate accuracy classification to be achieved. If project requirements are higher order, refer also to the FGCS Standards and Specifications for Geodetic Control Networks (FGCS 1984).

d. Resection. Three point resection is a form of triangulation. Three point resection may be used in areas where existing control points cannot be occupied or when the work does not warrant the time and cost of occupying each station. Triangulation of this type will be considered Fourth Order, although Third Order accuracy can be obtained if a strong triangular figure is used and the angles are accurately measured. The following minimum guidelines should be followed when performing a three point resection:

(1) Location. Points for observation should be selected so as to give strong geometric figures such as with angles between 60 and 120 degrees of arc.

(2) Redundancy. If it is possible to sight more than three control points, the extra points should be included in the figure. If possible, occupy one of the control stations as a check on the computations and to increase the positioning accuracy. Occupation of a control station is especially important if it serves as a control of the bearing or direction of a line for a traverse that originates from this same point.

(3) Measurements. Both the interior and exterior angles shall be observed and recorded. The sum of these angles shall not vary by more than 3 arc-seconds per angle from 360 degrees. Each angle will be turned not less than 2-4 times (in direct and inverted positions).

5-7. Bearing and Azimuth Determination

a. Bearing types. The bearing of a line is the direction of the line with respect to a given meridian. A bearing is indicated by the quadrant in which the line falls and the acute angle that the line makes with the meridian in that quadrant. Observed bearings are those for which the actual bearing angles are measured, while calculated bearings are those for which the bearing angles are indirectly obtained by calculations. A true bearing is made with respect to the astronomic north reference meridian. A magnetic bearing is one whose reference meridian is the direction to the magnetic poles. The location of the magnetic poles is constantly changing; therefore the magnetic bearing between two points is not constant over time. The angle between a true meridian and a magnetic meridian at the same point is called its magnetic declination. An assumed bearing is a bearing whose prime meridian is assumed. The relationship between an assumed bearing and the true meridian should be defined, as is the case with most state plane grid coordinate systems.

b. Bearing determination guidelines. All bearings used for engineering applications will be described by degrees, minutes, and seconds in the direction in which the line is progressing. Bearings are recorded with respect to its primary direction, north or south, and next the angle east or west. For example, a line can be described as heading north and deflected so many degrees east or west. Alternatively, a line also can be described as heading south and deflected so many degrees east or west. A bearing will never be listed with a value over 90 deg (i.e., the bearing value always will be between over 0 deg and 90 deg.

c. Azimuth types. The azimuth of a line is its direction as given by the angle between the meridian and the line, measured in a clockwise direction. Azimuths can be referenced from either the south point or the north point of a meridian. Assumed azimuths are often used for making maps and performing traverses, and are determined in a clockwise direction from an assumed meridian. Assumed azimuths are sometimes referred to as "localized grid azimuths". Azimuths can be either observed or calculated. Calculated azimuths consist of adding to or subtracting field observed angles from a known bearing or azimuth to determine a new bearing or azimuth.

d. Azimuth determination guidelines. Azimuths will be determined as a line with a clockwise angle from the north or south end of a true or assumed meridian. For traverse work using angle points, the closure requirements in Table 5-1 will be followed.

e. Astronomic azimuth. In order to control the direction of a traverse, an astronomic azimuth must be observed at specified intervals and abrupt changes of direction of the traverse. Astronomic azimuth observations can be made by the well-known hour angle or altitude methods. Azimuth observations should be divided evenly between the backsight and foresight stations as reference objects. Using the rear station, turn clockwise to forward station then to star, reverse telescope on star, then forward station and back to rear station. Then using forward station, turn clockwise to rear station then to star, reverse telescope on star, then rear station and back to forward station. The number of position repetitions will depend upon the order of accuracy required.

f. Position. For Second Order traverse, the observation of position for a Laplace azimuth will depend upon the use of the traverse. The project instructions typically will specify when an astronomic position is required. For some traverses, it may be necessary to observe astronomic positions to obtain the starting and terminating azimuth data; however, such practices are now largely obsolete goven GPS positioning capabilities.

5-8. Mandatory Requirements

The traverse closure requirements in Table 5-1 are mandatory.